II. "On some Phenomena exhibited by Gun-cotton and Gunpowder under special conditions of Exposure to Heat." By F. A. Abel, F.R.S. Received March 29, 1864.

The experiments upon which I have been engaged for some time past, in connexion with the manufacture and properties of gun-cotton, have brought under my notice some interesting points in the behaviour of both gun-cotton and gunpowder, when exposed to high temperatures, under particular conditions. I believe that these phenomena have not been previously observed, at any rate to their full extent, and I therefore venture to lay before the Royal Society a brief account of them.

Being anxious to possess some rapid method of testing the uniformity of products obtained by carrying out General von Lenk's system of manufacture of gun-cotton, I instituted experiments for the purpose of ascertaining whether, by igniting equal weights of gun-cotton of the same composition, by voltaic agency, within a partially exhausted vessel connected with a barometric tube, I could rely upon obtaining a uniform depression of the mercurial column, in different experiments made in atmospheres of uniform rarefaction, and whether slight differences in the composition of the gun-cotton would be indicated, with sufficient accuracy, by a corresponding difference in the volume of gas disengaged, or in the depression of the mercury. I found that, provided the mechanical condition of the gun-cotton, and its position with reference to the source of heat, were in all instances the same, the indications furnished by these experiments were sufficiently accurate for practical purposes. Each experiment was made with fifteen grains of gun-cotton, which were wrapped compactly round the platinum wire; the apparatus was exhausted until the column of mercury was raised to a height varying from 29 inches to 29·5 inches. The flash which accompanied the deflagration of the gun-cotton was apparently similar to that observed upon its ignition in open air; but it was noticed that an interval of time always occurred between the first application of heat (or incandescence of the wire) and the flashing of the gun-cotton, and that during this interval there was a very perceptible fall of the column of mercury. On several occasions, when the gun-cotton, in the form of "roving," or loosely twisted strand, was only laid over the wire, so that it hung down on either side, the red-hot wire simply cut it into two pieces, which fell to the bottom of the exhausted vessel, without continuing to burn. As these results appeared to indicate that the effects of heat upon gun-cotton, in a highly rarefied atmosphere, differed importantly from those observed under ordinary circumstances, or in a very imperfect vacuum, a series of experiments, under variously modified conditions, was instituted, of which the following are the most important.

It was found in numerous experiments, made with proportions of gun-cotton varying from one to two grains, in the form of a loose twist laid double, that in highly rarefied atmospheres (the pressure being varied

from 1 to 8 in inches of mercury) the gun-cotton, when ignited by means of the platinum wire, burned very slowly, presenting by daylight an appearance as if it smouldered, with little or no flame attending the combustion. I was at first led by these results to conjecture that this peculiar kind of combustion of the gun-cotton was determined solely by its ignition in atmospheres rarefied beyond a certain limit; and I was induced, in consequence, to institute a number of experiments with the view of ascertaining what was the most highly rarefied atmosphere in which gun-cotton would burn as in the open air—with a flash, accompanied by a body of bright flame. In order to ensure uniformity in the degree of heat applied to the cotton in these experiments, the platinum wire employed was sufficiently thin to be instantaneously melted on the passage of the voltaic current. About fifty different experiments were made with equal quantities of gun-cotton (0·2 grain), placed always in the same position, so that the platinum wire rested upon the material. A tolerably definite limit of the degree of rarefaction was arrived at, within which the gun-cotton was exploded instantaneously, as in the open air. When the pressure of air in the apparatus was reduced to 8·2 in inches of mercury, the gun-cotton still exploded with a flash, but not quite instantaneously; on reducing the pressure to 8 inches, the cotton underwent the slow kind of combustion in the majority of cases; on a few occasions it exploded with a flash of flame. The same occurred in a succession of experiments, until the pressure was reduced gradually to 7·7 inches, when instances of the rapid explosion of gun-cotton were no longer obtained.

Although these results were moderately definite when the conditions of the experiments were as nearly as possible uniform, it was found that they could be altered by slight modifications of any one particular condition (such as the quantity of gun-cotton, its mechanical condition, its position with reference to the source of heat, the quantity of heat applied, and the duration of its application). In illustration of this, the following results may be quoted.

If the gun-cotton was wrapped round, instead of being simply placed across the wire, its instantaneous combustion was effected in atmospheres considerably more rarefied than with the above experiments.

In employing a small piece of gun-cotton (0·3 of an inch long and weighing 0·3 to 0·4 of a grain) loosely twisted, laid across the wire, or upon a support immediately beneath the latter so that the wire rested upon it, the slow combustion established in it by the heated wire, under greatly diminished atmospheric pressure (amounting to 0·6 inch in this and the following experiments), proceeded uniformly towards each end of the piece of twist, until the whole was transformed into gas. But if a piece of the same twist, of considerably greater length (say 4 inches long and weighing about 2 grains), was exposed to heat in an atmosphere of the same rarefaction, the gun-cotton being laid over the wire and hanging down on either side, it was cut through by the passage of the current, and

the two pieces, falling to the bottom of the vessel, ceased to burn almost immediately. Of a piece of gun-cotton weighing 2·17 grains, there remained unchanged 1·80 gr.; the quantity burned amounted therefore to 0·37 gr., and corresponded closely to the quantity which was completely burned in the preceding experiments. (The depression of the mercurial column in this experiment, by the gases generated from the gun-cotton, amounted to 0·2 inch.)

A piece of the twist, $1\frac{1}{2}$ inch long, was placed across the wire, and supported by a plate of plaster of Paris, fixed immediately beneath it. The current was established to an extent just sufficient to heat the wire to the point of ignition of the gun-cotton, and then interrupted. The twist burned slowly in both directions until about a quarter of an inch was consumed on either side of the wire, when the combustion ceased. The same result was obtained in repetitions of the experiment, the wire being at once raised to a red heat, and thus maintained until the gun-cotton ceased to burn. But upon increasing the battery-power, doubling the thickness of the wire, and maintaining the heat, while a similar piece of twist was burning in both directions, the slow combustion continued until the entire quantity was transformed into gas. The same result was obtained by repeating this experiment with similar and larger quantities of gun-cotton, placed in the same position as before with reference to the wire.

In the next experiment, the mass of cotton exposed at one time to heat was increased by doubling a piece of the twist (4 inches long) and laying it thus doubled across the wire, as before. The current was allowed to pass until the wire was heated just sufficiently to ignite the gun-cotton, and then interrupted. In this case the slow combustion proceeded throughout the entire mass of the cotton. The permanent depression of mercury in this experiment was 0·6 inch. It was particularly noticed on this occasion, that, as the decomposition of the gun-cotton crept slowly along the mass, the burning portions or extremities of twist were surrounded by a beautiful green light, more like a phosphorescence than a flame, and in form something similar to the brush of an electric discharge.

Eight inches of the twist were laid fourfold over the wire, which was heated just sufficiently to ignite the cotton. The decomposition proceeded, as before, gradually throughout the mass of the gun-cotton, but became somewhat more rapid towards the end, when the green glow, observed at first, was superseded by a pale yellowish lambent flame, very different in appearance from the flame which accompanies the combustion of gun-cotton under ordinary conditions. The permanent depression of the column of mercury in this experiment was 1·2 inch.

The various modifications in the nature and extent of combustion which gun-cotton may be made to undergo, as demonstrated by the above experiments, when exposed to heat in highly rarefied atmospheres under variously modified conditions, are evidently due to the same causes which affect the rate of combustion of fuses under different atmospheric pressures, and which

have already been pointed out by Frankland in his interesting paper on the influence of atmospheric pressure upon some of the phenomena of combustion. The heat furnished by an incandescent or melting platinum wire is greatly in excess of that required to induce perfect combustion in gun-cotton which is actually in contact with, or in close proximity to it; and the heat resulting from this combustion, which is contained in the products of the change, will suffice to cause the transformation of the explosion to proceed from particle to particle. But if the pressure of the atmosphere in which the gun-cotton is submitted to the action of heat be reduced, the gases resulting from the combustion of the particles nearest to the source of heat will have a tendency, proportionate to the degree of rarefaction of the air, to pass away into space, and thus to convey away from proximity to the cotton, more or less rapidly and completely, the heat necessary to carry on the combustion established in the first particles. Thus, when the heated wire is enveloped in a considerable body of gun-cotton, the ignition of the entire mass is apparently not instantaneous, if attempted in a highly rarefied atmosphere, because the products of the combustion first established in the centre of the mass of gun-cotton escape rapidly into space, conveying away from the point of combustion the heat essential for its full maintenance; the gun-cotton therefore undergoes at first an imperfect form of combustion, or a kind of metamorphosis different from the normal result of the action of heat upon this material. But the effects of the gradual generation of heated gases from the interior of the mass of cotton are, to impart some of their heat to the material through which they have to escape, as well as gradually to increase the pressure of the atmosphere in the vessel, and thus to diminish the rapidity of their escape; hence a condition of things is in time arrived at when the remainder of the gun-cotton undergoes the ordinary metamorphosis, a result which is accelerated by maintaining the original source of heat. If, however, the gun-cotton be employed in a compact form (in the form of twist or thread), and placed only in contact with the source of heat at one point, the heat will be so effectually conveyed away by the escaping gases, that the material will undergo even what may be termed the secondary combustion or metamorphosis for a limited period only; so that, if a sufficient length of gun-cotton be employed, it will after a short time cease to burn, even imperfectly, because the heat essential for the maintenance of any chemical activity is soon completely abstracted by the escaping gases. These results may obviously be modified in various ways, as shown in the experiments described: thus, by increasing and maintaining the source of heat independent of the burning cotton, the slow combustion may be maintained through a much greater length of the material until the pressure of the atmosphere is increased, by the products disengaged, to an extent sufficient to admit of a more rapid and perfect metamorphosis being established in the remainder of the material; or the same result may be attained, independently of the continued application of external heat, by employing a thicker mass of cotton, or by using the

material in a less compact form. In these cases the maintenance of the chemical change is favoured either by radiation of heat to the cotton, and provision of additional heat, from an external source, to the gases as they escape and expand, or by establishing the change in a greater mass of the material, and thus reducing the rapidity with which the heat will be conveyed away by the escaping gases, or, finally, by allowing the gases, as they escape, to pass to some extent between the fibres of the cotton, and thus favouring the transmission of heat to individual particles of the material.

In the description of the two experiments last referred to above, I have stated that some peculiar phenomena were observed to attend the imperfect kind of combustion induced in the gun-cotton in rarefied atmospheres.

In order to examine these phenomena more closely, I instituted a series of experiments, in a darkened room, with equal quantities of gun-cotton ($\frac{1}{2}$ inch of twist=0·3 gr.) placed always in the same position, across the platinum wire, the only varying element in the experiment being the pressure of the atmosphere in the vessel, which was gradually increased. The following were the results observed :—

Experiment I.—Pressure=0·62 inch. The wire was heated just sufficiently to ignite the material; the current was then interrupted. The gun-cotton burned very slowly in both directions, emitting only the small green phosphorescent flame, or brush, already described.

Exp. II.—Pressure=1 inch. In addition to the green glow which surrounded the burning ends, a very faint yellowish flame was observed hovering over the gun-cotton.

Exp. III.—Pressure=1·5 inch. The cotton burned a little faster, and the faint yellowish flame was of a more decided character; indeed two separate flames were observed, each following up the green light as the cotton burned in the two directions.

Exp. IV.—Pressure=2 inches. The results were the same as in the preceding experiment, excepting that the yellowish flames became more marked.

Exp. V.—Pressure=2·5 inches. The same phenomena, the cotton burning considerably faster.

Exp. VI.—Pressure=3 inches. The same phenomena, the yellow flames increasing in size.

Exp. VII.—Pressure=4 inches. The rapidity of combustion of the cotton increased again considerably; the other phenomena observed were as before.

Exp. VIII.—Pressure=6 inches. The pale yellow flame had increased in size considerably, no longer forming a tongue, as in the preceding experiments, but completely enveloping the burning ends of the gun-cotton. The green glow, though much reduced, was still observed immediately round the burning surfaces.

Exp. IX.—Pressure=8 inches. The green glow was only just perceptible in this instance, and the cotton burned very rapidly, almost with the

ordinary flash; but the flame was still of a pale yellow. In the preceding experiments clouds of white vapour were observed after the decomposition of the gun-cotton; in this and the following experiments this white vapour was produced in much smaller proportion.

Expts. X. *to* XV. *inclusive.*—Pressure=10, 12, 14, 18, 20, 24 inches. The phenomena observed in these experiments did not differ in any important degree from those of Experiment IX.

Exp. XVI.—The same pressure (24 inches) was employed as in the last experiment, but the piece of gun-cotton-twist was laid double across the wire. In this instance the gun-cotton burned with a bright yellow flash, as in open air.

Exp. XVII.—Pressure=26 inches. The gun-cotton was laid singly over the wire, as in all experiments but the last. It burned with a flash o bright light, as in open air.

It appears from these experiments that gun-cotton, when ignited in small quantities in rarefied atmospheres, may exhibit, during its combustion, three distinct luminous phenomena. In the most highly rarefied atmospheres, the only indication of combustion is a beautiful green glow or phosphorescence which surrounds the extremity of the gun-cotton as it is slowly transformed into gases or vapours. When the pressure of the atmosphere is increased to one inch (with the proportion of gun-cotton indicated), a faint yellow flame appears at a short distance from the point of decomposition; and as the pressure is increased this pale yellow flame increases in size, and eventually appears quite to obliterate the green light. Lastly, when the pressure of the atmosphere and consequently proportion of the oxygen in the confined space is considerable, the cotton burns with the ordinary bright yellow flame. There can be no doubt that this final result is due to the almost instantaneous secondary combustion, in the air supplied, of the inflammable gases evolved by the explosion of the gun-cotton. It was thought that the pale yellow flame described might also be due to a combustion (in the air still contained in the vessel) of portions of the gases resulting from the decomposition of the gun-cotton; but a series of experiments, in which nitrogen, instead of air, constituted the rarefied atmosphere, showed that this could not be the case. The results obtained in these experiments corresponded closely to those above described, as far as relates to the production of the green glow and of the pale yellow flame. With rarefied atmospheres of nitrogen ranging down to one inch of pressure, the green flame was alone obtained; and the pale yellow flame, accompanying the green, became very marked at a pressure of 3 inches, as in the experiments with air.

It would seem probable from these results, that the mixture of gaseous products obtained by the peculiar change which heat effects in gun-cotton in highly rarefied atmospheres, contains not only combustible bodies, such as carbonic oxide, but also a small proportion of oxidizing gas (possibly protoxide of nitrogen, or even oxygen), and that when the pressure of the

atmosphere is sufficiently great this mixture, which has self-combustible properties, retains sufficient heat as it escapes, to burn, more or less completely, according to the degree of rarefaction of the atmosphere.

A series of experiments instituted with gun-cotton in highly rarefied atmospheres of oxygen, showed that the additional proportion of this gas thus introduced into the apparatus, beyond that which would have been contained in it with the employment of air of the same rarefaction, affected in a very important manner the behaviour of the explosion under the influence of heat. If eight or ten grains of gun-cotton are placed round the platinum wire, and the pressure of the atmosphere of oxygen in the vessel be reduced to four or three (in inches of mercury), the cotton explodes instantaneously, with an intensely bright flash, when the wire is heated. In a series of experiments made under gradually diminished pressures, oxygen being used instead of air, it was found that the gun-cotton exploded instantaneously, with a bright flash, until the pressure was reduced to 1·2 inch; from this pressure to that of 0·8 inch it still burned with a flash, but not instantaneously; and at pressures below 0·8 inch it no longer burned with a bright flash, but exhibited the comparatively slow combustion, accompanied by the pale yellow flame, which has been spoken of as observed when gun-cotton was ignited in air rarefied to pressures ranging from 1 inch to 24 inches.

The interesting phenomena exhibited by gun-cotton in highly rarefied atmospheres, induced me to make some experiments of a corresponding nature with gunpowder. The same apparatus was used as in the preceding experiments, but a small glass cup was fixed immediately beneath the platinum wire, so that, by bending the latter in the centre, it was made to dip into the cup, and could be covered by grains of gunpowder.

Two grains' weight of small grain gunpowder were heaped over the wire, and the pressure of air in the apparatus was reduced to 0·65 inch. The wire being heated to redness, three or four grains, in immediate proximity to it, fused in a short time and appeared to boil, evolving yellowish vapours, no doubt of sulphur. After the heat had been continued for eight or ten seconds, those particular grains deflagrated, and the remainder of the powder was scattered by the slight explosion, without being ignited. No appreciable depression of the mercurial column occurred during the evolution of the yellowish vapours; the permanent depression, after the deflagration, was only 0·15 inch.

The experiment was repeated with small-grain gunpowder, amounting to four grains, and the same phenomena were observed, with this difference, that a second slight deflagration followed shortly after the first, probably in consequence of a grain or two of the powder falling back into the cup.

A single piece of gunpowder, weighing 14 grains, so shaped as to remain in good contact with the wire, was placed over the latter, being supported by the cup. The pressure of air in the apparatus was, as before, equal to 0·65 inch of mercury. There was no perceptible effect for a short time

after the wire was first heated to redness; vapours of sulphur were then given off, and slight scintillations were occasionally observed; after a time the wire became deeply buried in the superincumbent mass of gunpowder, which fused, and appeared to boil, where it was in actual contact with the source of heat. After the lapse of three minutes from the commencement of the experiment, the powder deflagrated. The permanent depression of the mercury column amounted to 1·35 inch.

The experiment was repeated with a similar piece of powder, weighing 16 grains; the same phenomena were observed; and five minutes elapsed between the first heating of the wire and the deflagration of the powder.

The experiments were continued with fine-grained gunpowder, and under pressures gradually increased, in successive experiments, from ·07 to 3 in inches of mercury. The same weight of gunpowder (4 grains) was used in all the experiments. In those made under a pressure of 1 inch, the results observed were similar to those obtained in the first experiments; single grains of gunpowder were successively deflagrated, burning very slowly, and scattering but never igniting contiguous grains of powder. Eventually, after the lapse of from ten to twenty seconds, 3 or 4 grains were deflagrated at once, the remainder of the powder being thereby projected from the cup. At a pressure of 1·5 inch, the same phenomena were observed, but the successive deflagrations of fused grains of powder followed more quickly upon each other, and the final ignition of several together occurred in about ten seconds after the wire was first heated. At a pressure of 2 inches, at first only one or two of the fused grains were ignited, singly; and several were deflagrated together after the lapse of five seconds. A larger quantity of the powder was burned, but a portion was projected from the cup as in preceding experiments. At a pressure of 3 inches, no grains were ignited singly; the combustion of the powder was effected after an interval of about four seconds, and the greater portion was burned; the combustion, though it had gradually become more similar to that of gunpowder in open air, was still very slow.

Experiments made with gunpowder in highly rarefied atmospheres of nitrogen furnished results quite similar to those described; nor was any important difference in the character of the phenomena observed when oxygen was substituted for air, except that the scintillations and deflagrations of the powder-grains were in some instances somewhat more brilliant.

The above experiments show that, when gunpowder is in contact with an incandescent wire in a highly rarefied atmosphere, the heat is, in the first instance, abstracted to so great an extent by the volatilization of the sulphur, that the particles of powder cannot be raised to the temperature necessary for their ignition, until at any rate the greater part of that element has been expelled from the mixture, in consequence of which the portions first acted upon by heat will have become less explosive in their character, and require, therefore, a higher temperature for their ignition than

in their original condition. The effect of the continued application of heat to the powder thus changed is, to fuse the saltpetre and to establish chemical action between it and the charcoal, which, however, only gradually and occasionally becomes so energetic as to be accompanied by deflagration, because the gas disengaged by the oxidation of the charcoal continues to convey away much of the heat applied, in escaping into the rarefied space. For the same reason, the grains of unaltered powder which are in actual contact with the deflagrating particles are not ignited by the heat resulting from the combustion, but are simply scattered by the rush of escaping gases, at any rate until the pressure in the vessel has been so far increased by their generation as to diminish the rapidity and extent of their expansion at the moment of their escape. The disengagement, first of sulphur-vapour and then of gaseous products of chemical change, unattended by phenomena of combustion, when gunpowder is maintained in contact with a red-hot wire in very highly rarefied atmospheres, are results quite in harmony with the observations made by Mitchell, Frankland, and Dufour, with regard to the retarding influence of diminished atmospheric pressure upon the combustion of fuses. The phenomena described are most strikingly exhibited by operating upon single masses of gunpowder, of some size, in the manner directed above, when the application of the red-hot wire may be continued from three to five minutes (the gases disengaged during that period depressing the column of mercury from 0·5 to 0·7 inch) before the mass is ignited. There is no doubt that the products of decomposition of the gunpowder, obtained under these circumstances, differ greatly from those which result from its explosion in confined spaces or in the open air under ordinary atmospheric conditions. In all the experiments conducted in the most highly rarefied atmospheres (at pressures of 0·5 to 1·5 in inches of mercury), the contents of the vessel, after the final deflagration of the powder, always possessed a very peculiar odour, similar to that of horse-radish, due to the production of some sulphur-compound; nitrous acid was also very generally observed among the products. It is readily conceivable that the chemical action established between the constituents of gunpowder, under the circumstances described, must be of a very imperfect or partial character, the conditions under which it is established being unfavourable to its energetic development.

In describing the phenomena which accompany the ignition of gun-cotton in atmospheres of different rarefaction, I have pointed out that, at pressures varying from one to twenty-four in inches of mercury, a pale yellow flame was observed, which increased in size with the pressure of the atmosphere; and that a flame of precisely the same character was produced in rarefied atmospheres of nitrogen. The experiments instituted in nitrogen show that the explosion of loose tufts of gun-cotton in atmospheres of that gas, even at normal pressures, was always attended with a pale yellow flash of flame, quite different from the bright flash produced by igniting gun-cotton in air. The same result was observed in atmospheres

of carbonic acid, carbonic oxide, hydrogen, and coal-gas. In operating with pieces of gun-cotton-twist or thread of some length instead of employing the material in loose tufts, the results obtained in the two last-named gases were very different from those observed in atmospheres of nitrogen, carbonic acid, and carbonic oxide. When ignited by means of a platinum wire (across which it is placed) in vessels filled with either of those two gases, and completely closed or open at one end, the piece of twist burned slowly and regularly, the combustion proceeding much more deliberately than if the same piece of gun-cotton had been ignited in the usual manner in air, and being accompanied by only a very small jet or tongue of pale yellow flame, which was thrown out in a line with the burning surface when the gun-cotton was ignited. The same result was obtained in currents of those gases when passed through a long, wide glass tube, along which the gun-cotton twist was laid, one end being allowed to project some distance into the air. The projecting extremity being ignited, as soon as the piece of twist had burnt up to the opening of the tube through which the gas was passing, the character of the combustion of the gun-cotton was changed from the ordinary to the slow form above described. On repeating this form of experiment in currents of hydrogen and of coal-gas, the ignited gun-cotton burned in the slow manner only a very short distance inside the tube, the combustion ceasing altogether when not more than from half an inch to one inch of the twist had burnt in the tube. The same result was observed when the current of gas was interrupted at the moment that the gun-cotton was inflamed. It was at first thought that this extinction of the combustion of gun-cotton by hydrogen and coal-gas might be caused by the very rapid abstraction of heat from the burning surface of gun-cotton in consequence of the diffusive powers of those gases; but when the experiments were made in perfectly closed vessels, the piece of gun-cotton-twist being ignited by means of a platinum wire, the combustion also ceased almost instantaneously. These effects, therefore, can only be ascribed to the high cooling-powers, by convection, of the gases in question. It was found, by a succession of experiments, that when nitrogen was mixed with only one-fifth of its volume of hydrogen the combustion of gun-cotton-twist in the mixture was very slow and uncertain (being arrested after a short time in some instances), and that a mixture of one volume of hydrogen with three of nitrogen prevented its combustion, like coal-gas.

The slow kind of combustion of gun-cotton, in the form of twist, which is determined by its ignition in currents or atmospheres of nitrogen, carbonic acid, &c. may also be obtained in a powerful current of atmospheric air, the thread of cotton being placed in a somewhat narrow glass tube. If, however, the air is at rest, or only passing slowly, the result is uncertain. In employing very narrow tubes into which the gun-cotton fits pretty closely, the combustion passes over into the slow form when it reaches the opening of the tube, and occasionally it will then continue throughout the length of the tube. In that case, while the gun-cotton

burns slowly along the tube, with a very small sharp tongue of pale flame, a jet of flame is obtained at the mouth of the tube, by the burning of the gas evolved by the decomposition of the gun-cotton. Sometimes, and especially when wider tubes are employed, the slow combustion will proceed only for a short distance, and then, in consequence of the ignition of a mixture of the combustible gases and air within the tube, the gun-cotton will explode with great violence, the tube being completely pulverized, and portions of unburnt cotton scattered by the explosion. If still wider tubes are employed, the cotton will flash into flame almost instantaneously throughout the tube directly the flame reaches the opening: in these cases the explosion is not violent; sometimes the tube escapes fracture, and at others is broken in a few places, or torn open longitudinally, a slit being produced in the tube directly over the gun-cotton. By using narrow tubes and gradually shortening the tube through which the gun-cotton was passed, pieces of the twist being allowed to project at both ends, it was found, upon inflaming the material which projected on one side, that the slow form of combustion, induced in it as soon as it burned into the tube, was maintained by that portion which burned in the open air on the other side, when the combustion had proceeded through the tube. Eventually, by the employment of a screen of wood or card-board containing a perforation of the same diameter as that of the gun-cotton-twist, through which the latter was partially drawn, the alteration of the combustion of the material from the ordinary to the slow kind was found to be invariably effected. On the one side of the screen, the gun-cotton burned with the ordinary flame and rapidity, until the combustion extended to the perforation, when the flame was cut off and the material on the opposite side of the screen burned only slowly, emitting the small-pointed tongue of pale yellow flame.

These results indicate that if, even for the briefest space of time, the gases resulting from the first action of heat on gun-cotton upon its ignition in open air are impeded from completely enveloping the burning extremity of the gun-cotton-twist, their ignition is prevented; and as it is the comparatively high temperature produced by their combustion which effects the rapid and more complete combustion of the gun-cotton, the momentary extinction of the gases, and the continuous abstraction of heat by them as they escape from the point of combustion, render it impossible for the gun-cotton to continue to burn otherwise than in the slow and imperfect manner, undergoing a transformation similar in character to destructive distillation.

These facts appear to be fully established by the following additional experimental results:—

1. If, instead of employing in the above experiments a moderately compact gun-cotton-twist, one of more open structure is used, it becomes difficult or even impossible to effect the described change in the nature of the combustion, by the means described, because the gases do not simply burn

at, or escape from, the extremity of the twisted cotton, but pass readily between the separated fibres of the material, rendering it difficult or impossible to divert them all into one direction; and hence they at the same time transmit the combustion from particle to particle, and maintain the heat necessary for their own combustion.

2. If a piece of the compactly twisted gun-cotton, laid upon the table, be inflamed in the ordinary manner, and a jet of air be thrown against the flame, in a line with the piece of cotton, but in a direction opposite to that in which the flame is travelling, the combustion may readily be changed to the slow form, because the flame is prevented from enveloping the burning cotton, and thus becomes extinguished, as in the above experiment.

3. Conversely, if a gentle current of air be so directed against the gun-cotton, when undergoing the slow combustion, that it throws back upon the burning cotton the gases which are escaping, it will very speedily burst into the ordinary kind of combustion. Or, if a piece of the gun-cotton-twist, placed along a board, be made to burn in the imperfect manner, and the end of the board be then gradually raised, as soon as the material is brought into a nearly vertical position, the burning extremity being the lowest, it will burst into flame.

By applying to the extremity of a piece of the compact twist a heated body (the temperature of which may range from 135° C. even up to a red heat), provided the source of heat be not very large in proportion to the surface presented by the extremity of the gun-cotton, the latter may be ignited with certainty in such a manner that the slow form of combustion at once ensues, the heat applied being insufficient to inflame the gases produced by the decomposition of the gun-cotton. By allowing the gun-cotton thus ignited to burn in a moderately wide tube, closed at one end, the inflammable gases produced may be burned at the mouth of the tube, while the gun-cotton is burning in the interior; or they may be ignited and the gun-cotton consequently inflamed, by *approaching* a flame, or a body heated to full redness, to the latter, in the direction in which they are escaping.

It need hardly be stated that these results are regulated by the degree of compactness of the gun-cotton, the size of the twist, and the dimensions of the heated body. Thus a small platinum wire heated to full redness, or the extremity of a piece of smouldering string, will induce the slow combustion in a thin and moderately compact twist; but a larger body, such as a thick rod of iron, heated only to dull redness, will effect the ignition both of the gun-cotton and of the gases evolved by the combustion of the first particles, so that the material will be inflamed in the ordinary manner. Similarly the red-hot platinum wire, or a stout rod heated to redness barely visible in the dark, if they are *maintained* in close proximity to the slowly burning surface of gun-cotton, will eventually cause the gases evolved to burst into flame. The more compact the twist of the gun-cotton, the more superficial is the slow form of combustion induced in

it, and a condition of things is readily attainable, under which the gun-cotton-twist will simply smoulder in open air, leaving a carbonaceous residue; and the heat resulting from this most imperfect combustion will be abstracted by the gases evolved more rapidly than it is generated, so that in a brief space of time the gun-cotton will cease to burn at all in open air *.

The remarkable facility with which the nature of combustion of gun-cotton in air or other gases may be modified, constitutes a most characteristic peculiarity of this substance as an explosive, which is not shared by gunpowder or explosive bodies of that class, and which renders it easily conceivable that this material is susceptible of application to the production of a comparatively great variety of mechanical effects, the nature of which is determined by slight modifications in its physical condition, or by what might at first sight appear very trifling variations of the conditions attending its employment.

There is little doubt that the products of decomposition of gun-cotton vary almost as greatly as the phenomena which attend its exposure to heat under the circumstances described in this paper. A few incidental observations indicative of this variation were made in the course of the experiments. Thus, in the instances of the most imperfect metamorphosis of gun-cotton, the products included a considerable proportion of a white vapour, slowly dissolved by water, as also small quantities of nitrous acid and a very large proportion of nitric oxide. The latter gas is invariably formed on the combustion of gun-cotton in air or other gases; but the quantity produced appears always to be much greater in instances of the imperfect or slow combustion of the material. The odour of the gases produced in combustions of that class is powerfully cyanic, and there is no difficulty in detecting cyanogen among the products. I trust before long to institute a comparative analytical examination of the products resulting from the combustion of gun-cotton under various conditions; meanwhile I have already satisfied myself, by some qualitative experiments, of the very great difference existing between the results of the combustion of gun-cotton in open air, in partially confined spaces, and under conditions precisely similar to those which attend its employment for projectile or destructive purposes. I have, for example, confirmed the correctness of the statement made by Karolyi in his analytical account of the products of decomposition of gun-cotton, that no nitric oxide or higher oxide of nitrogen is eliminated upon the explosion of gun-cotton under considerable pressure, as in shells. Coupling this fact with the invariable production of nitric oxide when gun-cotton is exploded in open air or partially confined spaces, there appears to be very strong reason for the belief that, just as the reduc-

* By enclosing in suitable cases solid cords, made up of two or more strands, and more or less compactly twisted, I have succeeded readily in applying gun-cotton to the production of fuses and slow-matches, the time of burning of which may be accurately regulated.

tion of pressure determines a proportionately imperfect and complicated transformation of the gun-cotton upon its exposure to heat, the results of which are more or less essentially of an intermediate character, so, conversely, the greater the pressure, beyond the normal limits, under which gun-cotton is exploded—that is to say, the greater the pressure exerted by it, or the resistance presented at the first instant of its ignition, the more simple are the products of decomposition, and the greater are the physical effects attending its explosion, because of the greater energy with which the chemical change is effected.

III. "On Magnesium." By Dr. T. L. Phipson, F.C.S. Communicated by Prof. G. G. Stokes, Sec. R.S. Received March 9, 1864.

(Extract.)

Iodine and Sulphur.—I find that iodine can be distilled off magnesium without attacking the metal in the least. In the same manner I distilled several portions of sulphur off magnesium without the metal being at all attacked.

Decomposition of Silicic Acid.—Heated for some time in a porcelain crucible with excess of anhydrous silica, the metal burns vividly if the air has access; and a certain quantity of amorphous silicium is immediately formed. Magnesium is therefore capable of reducing silicic acid at a high temperature. The reason why potassium and sodium cannot effect this is simply because these metals are highly volatile and fly off before the crucible has attained the proper temperature. Magnesium being much less volatile than the alkaline metals, takes oxygen from silica before volatilizing. If the silicic acid be in excess, a silicate of magnesia is formed at the same time; if the metal is in excess, much siliciuret of magnesium is produced. The presence of the latter is immediately detected by throwing a little of the product into water acidulated with sulphuric acid, when the characteristic phosphoric odour of siliciuretted hydrogen is at once perceived.

Decomposition of Boracic Acid.—With boracic acid the phenomena are rather different; the acid melts and covers the metal, so that it does not inflame even when the crucible is left uncovered. A certain quantity of boron is soon liberated, and the product forms a greenish-black mass, which oxidizes and becomes white in contact with water, and *disengages no odoriferous gas* in acidulated water.

Decomposition of Carbonic Acid.—I thought it would be interesting to try a similar experiment with carbonic acid. Accordingly dry carbonate of soda was heated with a little magnesium in a glass tube over a common spirit-lamp; and before the temperature had arrived at a red heat I observed that carbon was liberated abundantly, and magnesia formed.

Action of Alkalies.—A solution of caustic alkali or ammonia has little or no action upon magnesium in the cold.